Effect of Cultural Management Practices on Grain Quality of Two Rice Cultivars

R. J. Bryant,[1,2] M. Anders,[3] and A. M. McClung[1]

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ABSTRACT

To reduce fuel and labor costs and increase profits, farmers are trying new ways of growing rice (*Oryza sativa* L.). This includes changing crop rotations, tillage systems, and fertilization levels. There is little information on how these changes affect the cooking quality of rice. We therefore looked at the parameters associated with cooking and processing quality (apparent amylose, gelatinization temperature, lipid and protein contents, and pasting properties) of two U.S. long grains (Cybonnet and Wells) that were grown using two different tillage systems, standard rate and high rates of fertilization, and different crop rotations (continuous rice R-R, rice after soybeans R-SB, and rice after corn R-C). No differences in quality traits were observed among any of the tillage systems. Rice grown in continuous rice rotation had the lowest protein content of brown and milled rice (8.6 and 8.1%, respectively) as compared to the highest levels observed in the rice-soybean rotation (9.3 and 8.6%, respectively). Rice grown in continuous rice rotation also had higher peak viscosity than other crop rotations. Increasing the fertilization rate increased the protein content of brown rice and decreased peak, trough, and final viscosities. Apparent amylose content, gelatinization temperature, and lipid content were not affected by crop rotation or fertility; however, they were influenced by cultivar. Although the results indicated statistical differences for some quality parameters, the differences were small enough that they are unlikely to have a major impact on processing quality of long grain rice if co-mingled.

Rice (*Oryza sativa* L.) is a staple food for much of the world. In 2005, the United States ranked fourth in the world export market supplying ≈14% of the rice that enters world trade (USA Rice Federation 2007). In 2006, the United States produced 194 thousand Cwt of rice, 72% of which was long grain; in 2007, rice production was expected to increase to 197 thousand Cwt (NASS 2007). With crude oil prices increasing dramatically, there has been a decrease in rice acreage as a result of rising production costs associated with fuel-related expenses such as irrigation pumping costs, petroleum-based fertilizers, and equipment operation. In addition, increasing competition for water resources has caused farmers to drill deeper wells, which also increases irrigation costs. To cut costs and improve farm income, farmers are trying new ways of growing rice including planting rice like a row crop to reduce water usage; using rice in rotation with other crops to access diverse markets (i.e., biofuel crops like corn and soybeans); reduced or no tillage which reduces fuel, water, and labor costs; and increased fertilizer applications to optimize yield. However, there is no information available on the effect of these unconventional farming methods on rice quality.

Arkansas (AR) has been a major rice producing State for many years and produced 49% (96 thousand Cwt) of the U.S. rice crop in 2006 (NASS 2007), long grain rice was 92% (88 thousand Cwt) of that (Rice Situation and Outlook 2006). Therefore, cultural management practices that affect the quantity and quality of rice produced in Arkansas will greatly influence the U.S. rice market.

Crop rotation has been used for years by rice farmers to capitalize on other crops with lower production costs and to help control red rice, a major weed in rice production fields. In the past, most of the rice grown in Arkansas was planted in a crop rotation following soybeans. However, with the price of corn increasing because of it use in the ethanol market, some farmers are using rice in rotation with corn. To better understand the effect of crop rotation, tillage methods, and increased nitrogen applications have on rice production, Anders et al (2004) established a long-term study in 2000 at the University of Arkansas Rice Research and Extension Center near Stuttgart, AR. They showed that N uptake in rice was lower in continuous rice rotation compared with rice-soybean rotation (Anders et al 2005a). Wilson et al (2006) recommended increasing the amount of N applied by 22.4 kg/ha in continuous rice rotation systems compared with a rice-soybean rotation, although this would increase input costs. Although N application is important for high rice yields, it can also change the processing and cooking quality of rice by increasing the protein content or changing the amylose content in the rice grain (Juliano et al 1965; Perez et al 1990; Prakash et al 2002; Champagne et al 2007).

In the development of new cultivars, rice breeders are identifying cultivars with high productivity under a diversity of environmental conditions and cultural management practices. Although increasing yield potential of new cultivars is critical for sustainable production in the global market, breeders must also meet stringent physicochemical quality requirements as specified by the rice milling and processing industries before a new cultivar is accepted.

The objective of this study was to determine the effect of crop rotation tillage and fertilization practices adopted by U.S. rice farmers on the physicochemical properties that affect cooking and processing quality (Zhou et al 2002) of two commercially accepted long grain rice cultivars.

MATERIALS AND METHODS

Two U.S. Southern long grain rice cultivars (*Oryza sativa* L.), Cybonnet and Wells, were grown in a field experiment near Stuttgart, AR, at the Dale Bumpers National Rice Research Center/University of Arkansas Rice Research and Extension Center in 2006. Wells (Moldenhauer et al 2007) has been an important commercial cultivar and widely accepted by the industry since its release in 1999 and is currently the predominant cultivar in Arkansas grown on >160,000 ha. Cybonnet (Gibbons et al 2006) is a newer release, grown on limited acreage, but it has been accepted by all commercial rice mills (*personal communication*). Wells and Cybonnet belong to the conventional U.S. long grain market class and both have very similar grain dimensions (Gibbons et al 2006). The study was conducted on land that was precision-graded to a

[1] USDA-ARS, Dale Bumpers National Rice Research Center, 2890 Hywy 130 E., Stuttgart, AR 72160. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

[2] Corresponding author. Phone: 870-672-9300 Ext. 227. Fax: 870-673-7581. E-mail: rolfe.bryant@ars.usda.gov

[3] University of Arkansas Rice Research and Extension Center, 2900 Hwy 130 E., Stuttgart, AR 72160.

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0.15% slope; the initial soil samples showed a range of pH 5.6–6.2, with an average carbon and nitrogen content of 0.84% and 0.08%, respectively. The plot design used rotation as the main plot, tillage method as the split plot, and combinations of cultivar and fertility level as the strip-plots. The rotation systems included continuous rice (R-R), rice after soybeans (*Glycine max* L.) (R-SB), and rice after corn (*Zea mays* L.) (R-C). Tillage methods used included no tillage and conventional tillage (Anders et al 2004). Two fertility rates were applied at 1) preflood N = 98.9 kg/ha, phosphorus (P_2O_5) = 44.8 kg/ha, and potassium (K_2) = 67.2 kg/ha, which is the standard recommended rate; and 2) N = 168.0 kg/ha, P_2O_5 = 67.2 kg/ha, and K_2 = 100.8 kg/ha, which was the high rate.

Rough rice samples were collected after combine harvest of each plot, cleaned, dried to a 12% moisture content, and stored at 4°C and 50% relative humidity for one month. Brown rice was produced by dehulling rough rice using a testing husker (Grain Machinery, Miami, FL). Green and broken kernels were removed from the samples by hand to produce samples of similar maturity and uniformity. This was followed by milling (McGill No. 2, Grain Machinery, Miami, FL) according to standard protocol (Bautista and Siebenmorgen 2002) accepted by U.S. breeders and research agronomists. Whole milled rice was separated from the broken kernels using a Grainman shaker table with #10 screens (Grain Machinery).

The milled samples were ground (Cyclotec grinder, Foss North America, Eden Prairie, MN) to a 0.5-mm screen. All analytical tests were conducted in duplicate. Apparent amylose content was determined using a simplification of the method of Williams et al (1958) adapted to an autoanalyzer (Juliano 1971) using a standard curve constructed from cultivars with known absorbance at 600 nm and known apparent amylose content. Pasting properties were determined according to Approved Method 61-02 (AACC International 2000) using a Rapid Visco-Analyser (RVA, Model 4, Newport Scientific, Eden Prairie, MN) with Thermocline for Windows software (v.2.2). Pasting properties included 1) peak viscosity, maximum viscosity during heating; 2) trough, hot paste viscosity; 3) breakdown, peak – trough viscosity; 4) final viscosity, cold paste viscosity; 5) setback 1. final – peak viscosity, and 6) setback 2, final – trough viscosity. Viscosity was measured in rapid visco units (RVU) with one RVU equaling ≈12 cP. Nitrogen content was determined on ground brown and milled rice using a nitrogen analyzer (FP-2000, Leco, St. Joseph, MI) and reported as protein using 5.95 as a conversion factor. Lipid content was determined on ground brown rice using a Soxtec Avanti apparatus (Foss North America, Eden Prairie, MN).

Thermal properties were determined using a differential scanning calorimetry (DSC model 4100, Calorimetry Sciences, Spanish Fork, UT). The system includes a reference cell and three sample cells. Rice flour (1 mg) and water (2 mg) were placed in a Hastelloy ampule and subjected to one heating cycle. Samples were heated from 20 to 150°C at a heating rate of 1.5°C/min. Baseline subtractions were made on thermal curves. Thermal curves depicting starch gelatinization were characterized by three temperatures: gelatinization onset temperature (T_o) (onset of peak development), peak temperature (T_p) (temperature at which maximum heat flow occurred during the scanning cycle), and conclusion (T_c) (taken at the conclusion of peak development). The enthalpy associated with starch gelatinization (ΔH) was determined by drawing a line between (T_o) and (T_c) and determining the area under the curve. It is expressed as J/g dwb of rice flour. T_p was used to indicate the gelatinization temperature.

The effect of fertility, crop rotation, tillage, and cultivar were determined by analysis of variance (ANOVA) using SAS general linear model (v.9.1, SAS Institute, Cary, NC) and SYSTAT (Systat Software, v.7.01, San Jose, CA). Where appropriate, least square means were separated using Fisher's protected least significant difference (LSD) at the 0.05 level. In an initial analysis, most three-way and four-way interactions were not significant and were removed from the final analysis.

RESULTS AND DISCUSSION

No significant effects on grain quality were attributed to tillage treatments (data not shown). However, several aspects of rice grain quality were significantly affected by cultivar, rotation, the amount of nitrogen applied, and their interactions (Tables I and II). Crop rotation had a significant effect on milled rice protein and peak and trough viscosities of the RVA curve but no effect on other parameters measured. The trend in protein content due to crop rotation was the same for brown rice as that for milled rice. However, the significance level was lower for brown rice ($P <$ 0.09). Continuous rice rotation resulted in a lower protein content, 8.6 and 8.1% for brown rice and milled rice, respectively, than

TABLE I
Significance of *F* Tests for Grain Quality Parameters Evaluated Using Different Rice Cultivars, Fertility Levels, and Crop Rotations[a]

			Lipid (%)	Protein (%)	
Source of Variation	Apparent Amylose (%)	DSC (ΔH, J/g)	Brown Rice	Brown Rice	Milled Rice
Rotation	ns	ns	ns	ns	0.016
Fertility	ns	ns	ns	0.026	ns
Cultivar	0.001	0.035	0.001	0.051	0.009

[a] DSC, differential scanning calorimeter; ΔH, transition enthaphy.

TABLE II
Significance of *F* Tests for RVA Parameters in Response to Different Rice Cultivars, Fertility Levels, and Rotations[a]

	Rapid Visco Analysis Parameters					
Source of Variation	Peak	Trough	Final	Breakdown	SB 1	SB 2
Rotations	0.010	0.055	ns	ns	ns	ns
Fertility levels	0.001	0.006	0.002	0.047	0.034	ns
Cultivar	0.023	0.001	0.001	ns	0.001	0.001
Rot × Fert	ns	ns	ns	0.031	ns	ns
Fert × Cul	ns	ns	ns	ns	ns	ns
Rot × Cul	ns	ns	ns	0.006	ns	ns
Rot × Fert × Cul	ns	ns	ns	0.035	ns	0.035

[a] Rot, rotation; Fert, fertility; Cul, cultivar; Peak, peak viscosity; Trough, trough viscosity; Final, final viscosity; Breakdown, peak hold; SB 1, setback 1 (final × trough) ; SB 2, setback 2 (final × peak).

grain from the rice-soybean rotation which had 9.3 and 8.6% for the brown rice and milled rice, respectively. Protein content in the grain from the rice-corn rotation was not significantly ($P > 0.05$) different than the other two rotations. The area where the experiment was conducted is part of a long-term rotation study. In a three-year study at this site, Anders et al (2005b) showed that the N uptake for the R-R rotation was lower than that for the R-SB rotation, which was consistent with the reduction in grain protein content observed here. They also noted a decrease in grain yield with the R-R rotation.

RVA profile, also known as pasting curve, is an indication of cooking (Bergman et al 2004; Batey and Bason 2007) and processing quality. Peak viscosity was significantly affected by rotation ($P < 0.01$), whereas the significance of trough viscosity was $P < 0.06$ (Table II). The peak and trough viscosities were highest for continuous rice rotation (217 and 120 RVU, respectively) and lowest for the rice-corn rotation (209 and 113 RVU, respectively). Crop rotation did not have a significant effect on final viscosity, breakdown, setback 1, or setback 2. Protein content has an effect on peak viscosity by influencing the amount of water absorbed during cooking, thus changing the texture of cooked rice (Martin and Fitzgerald 2002). Other research has also shown that an increase in protein content will increase hardness and chewiness of cooked rice (Primo et al 1962; Tamaki et al 1989; Champagne et al 2007). Consistent with these reports, we observed continuous rice (R-R) rotation had the highest peak viscosity and the lowest protein content, whereas the peak viscosity of the R-C rotation was lower and protein content higher than the R-R rotation. However, R-SB rotation had the highest protein content but its peak viscosity was not the lowest (Fig. 1). This difference maybe due to a change in the protein fraction in the R-SB rotation as a result of the higher N uptake (Anders et al 2005b).

Fertility had a significant effect on the protein content in brown rice and on all RVA parameters, except setback 2 (Tables II and III). Its effect on milled rice protein followed the same trend as for brown rice, although the level of significance for milled rice was $P < 0.11$. Increasing fertility elevated the protein content in both brown rice (from 8.8 to 9.2%) and milled rice (from 8.2 to 8.6%). The concentration of protein is greater in the bran and periphery of the endosperm and decreases toward the center of the grain (Little and Dawson 1960). Thus it is expected that brown rice has higher protein content than milled rice. An increase in protein content due to increased fertilization was also seen in the three year study by Champagne et al (2007) where they looked at five cultivars under different fertility treatments. In this study, increased fertility significantly decreased all RVA viscosities (Table IV) except for setback 2, which did not change (Table III). However, changing protein content did not affect the peak viscosity the same when planted in different crop rotations. Milled rice protein content for the high fertility treatment was the same as in the R-SB rotation, however the peak viscosity was numerically lower than that found in the R-SB treatment (Tables III and IV, and Fig. 1). Protein contents observed in the standard fertility treatment and R-R rotation were numerically similar as were the peak viscosities. Thus, increased milled rice protein content, whether due to following soybean rotations or increased fertilizer application, was associated with a decrease in peak viscosity relative to continuous rice crop rotation and standard fertility practices. In contrast, peak viscosity values and the amount of milled rice protein observed in the R-C system did not follow this trend (Fig. 1). Results from this study indicate that higher N uptake by the plant may reduce peak viscosity but this may be confounded by the cropping system. Breakdown and setback viscosities are indicative of the stability of the starch to shear stress and heat, whereas final viscosity is an indication of the ability of rice to retrograde (Batey and Bason 2007). Although there were no significant interactions for other RVA parameters, breakdown and setback 2 viscosities had significant two- and three-way interactions (Table II). Analysis of the three-way interactions demonstrated that, in comparison to Wells, Cybonnet was more stable in breakdown and setback 2 viscosities regardless of fertility or crop rotation treatment (data not shown). Martin and Fitzgerald (2002) and Champagne et al (2007) both showed a negative correlation between peak and breakdown viscosity with protein content in response to fertility, which is in agreement with our data. Champagne et al (2007) also showed no significant correlation between setback 2 and protein. Martin and Fitzgerald speculated that the decrease in peak viscosity associated with an increase in N was due to re-

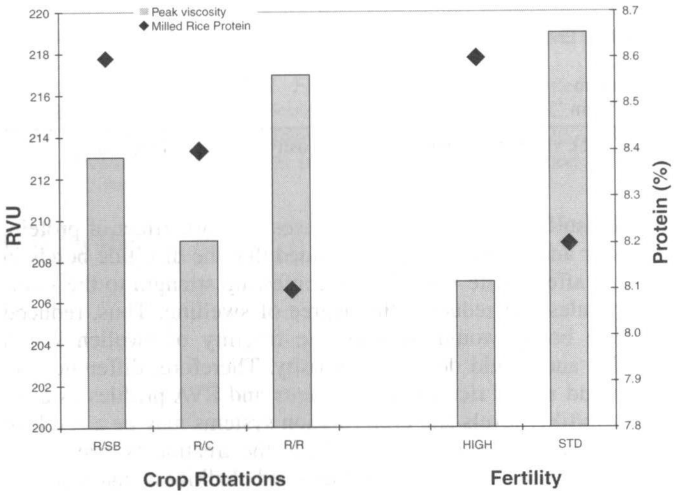

Fig. 1. Interaction of protein content and peak viscosity in milled rice with crop rotation and fertility. R/SB, rice/soybean rotation; R/C, rice/corn rotation; R/R, continuous rice rotation; High, high fertility; STD, standard fertility; 1 RVU, ≈12 cP. 211 × 140 mm (96 × 96 dpi).

TABLE III
Least Squares Means (LSM) Comparison[a] for Main Effects of Rotation, Fertility, and Cultivar for Grain Quality Parameters

	Apparent Amylose (%)		DSC (ΔH J/g)		Lipid (%)		Protein (%)			
Main Effect	LSM	LSD Grouping	LSM	LSD Grouping	LSM	LSD Grouping	LSM	LSD Grouping	LSM	LSD Grouping
Continuous rice	23.5	A	8.4	A	2.7	A	8.6[b]	A[b]	8.1[c]	A[c]
Rice – soybeans	23.5	A	8.5	A	2.6	A	9.3	A	8.6	B
Rice – corn	23.9	A	8.1	A	2.5	A	9.2	A	8.4	AB
Increased fertility	23.6	A	8.3	A	2.6	A	9.2	A	8.6	A
Standard fertility	23.7	A	8.4	A	2.6	A	8.8	B	8.2	A
Cybonnet	23.3	A	8.1	A	2.7	A	9.1	A	8.5	A
Wells	24.0	B	8.6	B	2.4	B	8.9	B	8.2	B

[a] Fisher's LSD at $P < 0.05$.
[b] Brown rice values.
[c] Milled rice values.

TABLE IV
Least Squares Means (LSM) Comparison for Main Effects of Rotation, Fertility, and Cultivar for RVA Parameters[a,b,c]

Main Effect	Peak LSM	Peak LSD Grouping	Trough LSM	Trough LSD Grouping	Final LSM	Final LSD Grouping	Breakdown LSM	Breakdown LSD Grouping	SB 1 LSM	SB 1 LSD Grouping	SB 2 LSM	SB 2 LSD Grouping
Continuous rice	217	A	120	A	237	A	96	A	118	A	21	A
Rice – soybeans	213	B	115	A	233	A	97	A	118	A	20	A
Rice – corn	209	C	113	A	232	A	96	A	119	A	23	A
Increased fertility	207	A	112	A	228	A	95	A	117	A	21	A
Standard fertility	219	B	120	B	240	B	98	B	120	B	21	A
Cybonnet	216	A	119	A	241	A	96	A	122	A	25	A
Wells	210	B	113	B	227	B	97	A	114	B	17	B

[a] Fisher's LSD at $P < 0.05$.
[b] Peak, peak viscosity; Trough, trough viscosity; Final, final viscosity; Breakdown, peak hold; SB 1, setback 1 (final × trough) ; SB 2, setback 2 (final × peak).
[c] 1 RVU ≈12 cP.

TABLE V
Simple Statistics Comparing Apparent Amylose Content and RVA Parameters of Cybonnet and Wells Evaluated in the Uniform Rice Regional Nursery Over Seven Southern U.S. Environments[a]

Statistics for Each Cultivar	Apparent Amylose (%)	RVA Parameters Peak	Trough	Final
Cybonnet				
Mean	22.0	272	146	286
Standard Error	0.36	7.67	5.27	6.17
Median	21.6	276	146	289
Minimum	21.0	240	122	252
Maximum	23.8	295	162	300
Wells				
Mean	22.0	282	152	287
Standard Error	0.38	6.84	5.96	6.22
Median	21.8	284	148	287
Minimum	20.7	249	128	257
Maximum	23.9	299	175	307

[a] Peak, peak viscosity; Trough, trough viscosity; Final, final viscosity.

duced disulfide bonding which reduces network effect of protein. Hamaker and Griffin (1993) concluded that the disulfide bonds in proteins affect paste viscosity by conferring strength to the swollen granules and reducing the degree of swelling. Thus, reduced disulfide bonds would increase the fragility of swollen starch granules and would decrease viscosity. Therefore, differences in brown and milled rice protein contents and RVA profiles as a result of fertility levels and crop rotation systems may be a result of differences in protein structure. Also, the treatments may affect other factors such as kernel hardness and chalkiness that were not measured in this study that may affect the degree of milling. Differences in milling degree affect cooking and processing quality (Perdon et al 2001).

Fertility did not significantly affect lipid content, gelatinization temperature, or amylose content. Champagne et al (2007) compared four cultivars grown using conventional fertilization rate, 50% conventional fertilization rate, and organic (chicken litter) fertilization. They found no significant difference in the apparent amylose content due to fertility over the three-year study.

DSC profile is used to determine the gelatinization temperature and enthalpy of rice (Bergman et al 2004). Gelatinization temperature, which is the temperature at which maximum energy input per unit time is required during gelatinization (cooking), was not affected by treatments (data not shown). However, enthalpy (ΔH), which is the energy required for complete gelatinization, was significantly ($P < 0.05$) affected by cultivar (Table I). We observed that these two cultivars have very similar gelatinization temperatures (Wells 78.1°C, Cybonnet 78.4°C) which suggests that they may differ slightly in starch structure.

Although results indicated that Wells and Cybonnet were significantly different for all parameters measured except gelatinization temperature (data not shown) and breakdown viscosity (Table II), they are classified the same by the industry as having conventional, long grain cooking quality (Moldenhauer et al 2004). In this study, Wells was identified as having higher amylose but lower protein and lipid contents along with a lower RVA profile and greater ΔH as compared to Cybonnet (Tables III and IV). Although these results indicate that at a statistical level Wells has lower viscosity and requires greater energy for starch gelatinization, the differences are small enough that they are unlikely to have a major impact on the processing quality if co-mingled. Moreover, results from the Uniform Rice Regional Nursery conducted over four years and three states demonstrated that these two cultivars are very similar in amylose contents and RVA parameters (Table V).

CONCLUSIONS

To maximize profits, rice growers must implement the latest technologies such as crop rotations and optimized fertilizer applications. Breeders try to develop new cultivars that can respond favorably to changes in cultural management practices while maintaining consistent cooking and processing quality. This allows millers and processors to co-mingle cultivars within a market class and still be assured of uniform quality for end users. This study demonstrated that different crop rotations and fertility levels influenced protein content and pasting viscosity profiles while no effect was observed on amylose content, lipid content of brown rice, or gelatinization temperature. Although the effects observed in this study were statistically significant, the magnitude of the differences were very small and would likely have little effect on cooking or processing quality. The two long grain cultivars evaluated in this study are considered very similar in cooking and processing quality. However, more diverse cultivars such as indicas, hybrids, short-grains, medium grains, or specialty rices that have different physicochemical traits need to be examined for their response to different cultural management practices. Our results suggest that rice cultivars that are developed to meet the long grain quality standards established by the U.S. rice industry will perform in a consistent manner for end users even when produced under a various cultural practices.

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